

- 1 A waveguide for an optical circuit comprising:
 - a substrate;
 - a deposited doped lower cladding layer;
 - a doped waveguide core formed from a layer of doped material deposited on the lower cladding layer; and
 - a deposited doped upper cladding layer embedding the waveguide core;wherein the waveguide core includes mobile dopant ions which have diffused from the deposited doped material of the waveguide core into the upper cladding layer and the lower cladding layer to form an ion diffusion region around said doped waveguide core such that the waveguide core boundary walls are substantially smooth.
2. A waveguide as claimed in Claim 1, wherein the ion diffusion region is isotropic with respect to the waveguide core, such that the waveguide core is substantially symmetric about the core axis.
3. A waveguide as claimed in either Claim 1 or Claim 2, wherein the ion diffusion region surrounding the waveguide core forms a substantially rounded waveguide core.
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4. A waveguide as claimed in Claim 3, wherein the rounded waveguide core is elliptical or circular in cross-section.
5. A waveguide as claimed in any one preceding claim, further including a buffer layer formed on the substrate and wherein the lower cladding layer is formed on the buffer layer.
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6. A waveguide as claimed in any one preceding claim, wherein the substrate comprises silicon and/or silica and/or sapphire.

7. A waveguide as claimed in Claim 6, wherein said buffer layer includes a thermally oxidised layer of the substrate.

8. A waveguide as claimed in any preceding claim, wherein the buffer layer comprises doped silica.

9. A waveguide as claimed in any preceding claim, wherein the thickness of the buffer layer is in the range 0.2 m to 20 m.

10. A waveguide as claimed in any preceding claim, wherein the lower cladding layer comprises doped silica.

11. A waveguide as claimed in any preceding claim, wherein the lower cladding layer includes at least one Phosphorus oxide and/or at least one Boron oxide.

12. A waveguide as claimed in Claim 11, wherein the lower cladding layer includes at least one Phosphorus oxide and at least one Boron oxide and wherein the Phosphorus oxide to Boron oxide ratio is such that the lower cladding layer refractive index is substantially equal to the refractive index of the buffer layer.

13. A waveguide as claimed in any preceding claim, wherein the lower cladding layer includes doped silica, at least one Phosphorus oxide and at least one Boron oxide and wherein the silica:Phosphorus oxide:Boron oxide ratio is in

the range of 75 to 95 wt% silica:1 to 7 wt% Phosphorus oxide:4 to 18 wt% Boron oxide.

14. A waveguide as claimed in Claim 13, wherein the lower cladding layer has a silica:Phosphorus oxide:Boron oxide ratio in the range of 80 to 90 wt% silica:2.5 to 6 wt% Phosphorus oxide:7.5 to 14 wt% Boron oxide.

15. A waveguide as claimed in Claim 14, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio of 82 wt% silica; to 5 wt% Phosphorus oxide; to 13 wt% Boron oxide.

16. A waveguide as claimed in any preceding claim, wherein the thickness of the lower cladding layer is 1 m to 20 m.

17. A waveguide as claimed in any preceding claim, wherein the waveguide core comprises doped silica.

18. A waveguide as claimed in any preceding claim, wherein said mobile dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or compounds of these elements.

19. A waveguide as claimed in any preceding claim, wherein dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or Aluminium and/or Boron and/or Germanium and/or Tin and/or Titanium and/or compounds of these elements.

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20. A waveguide as claimed in any preceding claim, wherein the waveguide core includes Phosphorus oxide and/or Boron oxide.

21. A waveguide as claimed in Claim 20, wherein the waveguide core comprises P_2O_5 - SiO_2 .

22. A waveguide as claimed in any preceding claim, wherein the refractive index of the waveguide core differs from that of the lower cladding layer by at least 0.05%.

23. A waveguide as claimed in any preceding claim, wherein the waveguide core includes silica, and at least one Phosphorus oxide and wherein the silica to Phosphorus oxide ratio is in the range of 75 to 95 wt% silica to 5 to 25 wt% Phosphorus oxide.

24. A waveguide as claimed in Claim 23, wherein the waveguide core has a silica to Phosphorus oxide ratio of 80 wt% silica to 20 wt% Phosphorus oxide.

25. A waveguide as claimed in any preceding claim, wherein the thickness of the waveguide core is in the range 2 m to 60 m.

26. A waveguide as claimed in Claim 25, wherein the thickness of the waveguide core is 6 m.

27. A waveguide as claimed in any preceding claim, wherein the lower cladding layer and the upper cladding layer refractive indices are substantially equal.

28. A waveguide as claimed in any preceding claim, wherein the lower cladding layer and the upper cladding layer comprise the same material.

Cut off > 29. A waveguide as claimed in any preceding claim, wherein the waveguide core has a mobile ion dopant concentration higher than the mobile ion dopant concentration of the lower cladding layer or the upper cladding layer.

30. A method of fabricating a waveguide comprising the steps of:

providing a substrate;
forming a doped lower cladding layer by deposition;
forming a doped core layer deposited on the lower cladding layer;
forming a waveguide core from the core layer;
depositing a doped upper cladding layer to embed the waveguide core; and
causing mobile ion dopants included in the core layer to undergo diffusion from the waveguide core into the surrounding upper cladding layer and lower cladding layer to form an ion diffusion region around the waveguide core such that the waveguide core boundary walls are substantially smooth.

31. A method as claimed in Claim 30, wherein the diffusion of the said mobile dopant ions from the waveguide core is such that a waveguide core is formed which is substantially symmetric about the core axis.

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32. A method as claimed in either Claim 30 or 31, wherein the diffusion of the said mobile dopant ions from the waveguide core swells the boundary walls of the waveguide core.

33. A method as claimed in Claim 32, wherein the diffusion of the said mobile dopant ions swells the boundary walls of the waveguide core to form a substantially rounded waveguide core.

34. A method as claimed in Claim 33, wherein the rounded waveguide core is elliptical or circular in cross-section.

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35. A method as claimed in any one of Claims 30 to 34, and including the step of forming a buffer layer on the substrate.

36. A method as claimed in Claim 35, wherein the lower cladding layer is formed on said buffer layer.

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37. A method as claimed in any of Claims 30 to 36, wherein the steps of forming each of the lower cladding layer, the core layer and the upper cladding layer comprise the steps of:

depositing each layer; and
at least partially consolidating each layer.

38. A method as claimed in Claim 37, wherein any of the lower cladding layer, the core layer and the upper cladding layer partially consolidated after deposition is fully consolidated with the full consolidation of any other of

the lower cladding layer, the core layer or the upper cladding layer.

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39. A method as claimed in any of Claims 30 to 38, wherein the diffusion of mobile ion dopants in the core layer occurs during the consolidation of the lower cladding layer and/or the upper cladding layer.

40. A method as claimed in any of Claims 30 to 39 further comprising at least one thermal processing step after the formation of the upper cladding layer, wherein during said thermal processing of the waveguide the mobile ion dopants in the core layer undergo diffusion into the surrounding layers.

41. A method as claimed in any of Claims 30 to 40, wherein the substrate comprises silicon and/or silica and/or sapphire.

42. A method as claimed in any of Claims 30 to 41, wherein the buffer layer includes a thermally oxidised layer of the substrate.

43. A method as claimed in any of Claims 30 to 42, wherein the buffer layer comprises doped silica.

44. A method as claimed in any of Claims 30 to 43, wherein the thickness of the buffer layer formed is in the range of 0.2 m to 20 m.

45. A method as claimed in any one of Claims 30 to 44, wherein the lower cladding layer comprises doped silica.

46. A method as claimed in any one of Claims 30 to 45, wherein the lower cladding layer includes at least one Phosphorus oxide and/or Boron oxide.

47. A method as claimed in Claim 46, wherein the lower cladding layer includes at least one Phosphorus oxide and at least one Boron oxide and wherein the Phosphorus oxide to Boron oxide ratio is such that the lower cladding layer refractive index is substantially equal to the refractive index of the buffer layer.

48. A method as claimed in any of Claims 30 to 47, wherein the lower cladding layer includes silica, at least one Phosphorus oxide and at least one Boron oxide and wherein the silica; to Phosphorus oxide; to Boron oxide ratio in the range of 75 to 95 wt% silica; to 1 to 7 wt% Phosphorus oxide; to 4 to 18 wt% Boron oxide.

49. A method as claimed in Claim 48, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio in the range of 80 to 90 wt% silica; to 2.5 to 6 wt% Phosphorus oxide; to 7.5 to 14 wt% Boron oxide.

50. A method as claimed in Claim 51, wherein the lower cladding layer has a silica; to Phosphorus oxide; to Boron oxide ratio of 82 wt% silica; to 5 wt% Phosphorus oxide; to 13 wt% Boron oxide.

51. A method as claimed in any of Claims 30 to 50, wherein the thickness of the lower cladding layer is 1 m to 20 m.

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52. A method as claimed in any of Claims 30 to 51, wherein the core layer comprises *doped silica*.

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53. A method as claimed in any of Claims 30 to 51, wherein said mobile dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or compounds of these elements.

54. A method as claimed in any of Claims 30 to 53, wherein dopant ions of the waveguide core include Phosphorus and/or Fluorine and/or Aluminium and/or Boron and/or Germanium and/or Tin and/or Titanium and/or compounds of these elements.

55. A method as claimed in any of Claims 30 to 54, wherein the core layer includes Phosphorus oxide and/or Boron oxide.

56. A method as claimed in Claim 55, wherein the core layer comprises $P_2O_5-SiO_2$.

57. A method as claimed in any of Claims 30 to 56, wherein the refractive index of the waveguide core differs from that of the lower cladding layer by at least 0.05%.

58. A method as claimed in any of Claims 30 to 57, wherein the waveguide core includes silica and at least one Phosphorus oxide and wherein the silica to Phosphorus oxide ratio is in the range of 75 to 95 wt% silica to 5 to 25 wt% Phosphorus oxide.

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59. A method as claimed in Claim 58, wherein the waveguide core has a silica to Phosphorus oxide ratio of 80 wt% silica to 20 wt% Phosphorus oxide.

60. A method as claimed in any of Claims 30 to 59, wherein the thickness of the waveguide core is in the range 2 m to 60 m.

61. A method as claimed in Claim 60, wherein the thickness of the waveguide core is 6 m.

62. A method as claimed in any of claims 35 to 51, wherein said lower cladding layer and said buffer layer are formed substantially in the same step.

63. A method as claimed in any of claims 37 to 62, wherein the consolidation of the lower cladding layer is at a temperature or temperatures in the range 950°C to 1400°C.

64. A method as claimed in Claim 63, wherein the consolidation of the lower cladding layer is at a temperature or temperatures in the range 1100°C to 1350°C.

65. A method as claimed in any of Claims 37 to 64, wherein the consolidation of the core layer is at a temperature or temperatures in the range 950°C to 1400°C.

66. A method as claimed in Claim 65, wherein the consolidation of the core layer is at a temperature or temperatures in the range 1100°C to 1385°C.

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67. A method as claimed in any of Claims 37 to 66, wherein the consolidation of the upper cladding layer is at a temperature or temperatures in the range 950°C to 1400°C.

68. A method as claimed in Claim 67, wherein the consolidation of the upper cladding layer is at a temperature or temperatures in the range 1100°C to 1350°C.

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69. A method as claimed in any of Claims 37 to 68, wherein the temperature or temperature range at which the lower cladding layer is consolidated is greater than the temperature or temperature range at which the core is consolidated.

70. A method as claimed in any of Claims 37 to 69, wherein the temperature or temperature range at which the upper cladding layer is consolidated is substantially equal to the temperature or temperature range at which the core layer is consolidated.

71. A method as claimed in any of Claims 37 to 69, wherein at least one of the lower cladding layer, the core layer, and the upper cladding layer is deposited by a Flame Hydrolysis Deposition process and/or Chemical Vapour Deposition process.

72. A method as claimed in Claim 71, wherein the Chemical Vapour Deposition process is a Low Pressure Chemical Vapour Deposition process or a Plasma Enhanced Chemical Vapour Deposition process.

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73. A method as claimed in any of Claims 37 to 72, wherein the consolidation is by fusing using a Flame Hydrolysis Deposition burner.

74. A method as claimed in any of Claims 37 to 72, wherein the consolidation is by fusing in a furnace.

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75. A method as claimed in either of Claims 73 or 74, wherein the step of fusing the lower cladding layer and the step of fusing the core layer are performed simultaneously.

76. A method as claimed in any of Claims 30 to 75, wherein the ion diffusion region is isotropic with respect to the waveguide core.

77. A method as claimed in any of Claims 30 to 76, wherein the waveguide core formed from the core layer is square or rectangular in cross-section.

78. A waveguide as claimed in any one of Claims 1 to 29, wherein the waveguide core formed from the core layer is square or rectangular in cross-section.

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79. A method as claimed in any of Claims 30 to 78, wherein the waveguide core is formed from the core layer using a dry etching technique and/or a photolithographic technique and/or a mechanical sawing process.

80. A method as claimed in Claim 79, wherein the dry etching technique comprises a reactive ion etching process and/or a plasma etching process and/or an ion milling process.